Software-Defined Networks:

Architecture for Extended SDN Applications and Resource Optimization in Cloud Data Centers

Minh Pham

Supervisor

Professor Doan B. Hoang

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DEDICATION

I dedicated this thesis to my parents, Bay Tan Pham and Dao Thi Nguyen, who always encourage me to study to have a better life, to my brothers Thanh Minh Pham, Xuan Tu Pham and Minh Nhut Pham for their support and encouragement me to complete my study.

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Minh Nguyet Thi Pham, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering Faculty of Engineering and IT at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Signature of student: _____

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THE AUTHOR'S PUBLICATIONS

International Conferences Publications and Proceedings

Hoang, Doan & Pham, Minh, 2015, "On software-defined networking and the design of SDN controllers", presented at International conference of Network of the Future 2015, Montreal, Sep 30 – Oct 2, 2015, as a Poster

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ABSTRACT

Virtualization is the main mechanism to share resources to many customers by creating virtual resources on the common physical resources. The challenge is to search for an optimal resource allocation mechanism that maximizes the capacity of the virtual resources. Network virtualization needs a new virtual network embedding (VNE) mechanism that focuses concurrently on control congestion, cost saving, energy saving; a link embedding mechanism needs to select actively based on multiple objectives the physical link resources, network slicing requires a new resource allocation mechanism that satisfies latency constraints of 5G mobile system. This research investigated and developed solutions for resource request delivery, and optimal resource allocation in network virtualization and 5G core network slicing applying SDN technology.

In the research, firstly, the three-tier architecture applying micro-service architecture for extended SDN application is presented to facilitate the flexibility, in which new services are created or composed, existing services are reused. The evaluation is the prototype of the Dynamic resource allocation using the proposed architecture.

Secondly, the multiple-objective VNE that focuses on congestion avoidance, energy saving and cost saving (CEVNE) is presented. The novelty lies in the CEVNE mathematical model for multiple-objective optimization problems, and its nodes and link embedding algorithms. The evaluation showed that CEVNE outperformed The-State-Of-The-Art in acceptance ratio in the challenged, near-congestion scenarios.

Thirdly, the architecture to realize virtual link mapping in CEVNE is presented. The novelty is in the SDN-based heuristic algorithm, and the applying of the architecture for extended SDN applications. The research results in the realization of the active virtual link embedding process that focuses on multi-objective concurrently. The evaluation showed that the solution outperformed the traditional link mapping in all three objectives.

Fourthly, the mathematical model of the resource allocation optimization in latency-aware 5G core network slicing is presented. The novelties lie in the satisfaction of different latency requirements of 5G applications: eMBB, uRLLC, and mMTC, and the solution strategy to linearize, convex-relax and decompose the program into sub-problems. The evaluation shows that the solution

outperformed the The-State-Of-The-Art in resource allocation, execution time, latency satisfaction and the arrival rates.

In this thesis, the resource optimization problem and the architecture for extended SDN applications have been studied comprehensively. The results of this thesis can readily be applied to 5G vertical applications where resource optimization and network routing problems exist naturally in multiple domains and require software defined networking logically centralized control architecture for efficient and dynamic solutions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AI	Artificial Intelligence
ARP	Address resolution protocol
ARS	Approximate resource scarcity
ASR	Architecturally significant requirements
BPM	Business process management
C2X	Car to everything
CAM/ TCAM	Content addressable memory / Ternary content addressable memory
CAPEX	Capital expenditure
CEVNE	Congestion-aware energy-aware virtual network embedding
CEVNE NoM	Congestion-aware energy-aware virtual network embedding node embedding
CEVNE LiM	Congestion-aware energy-aware virtual network embedding link embedding
CL	Cloud computing
CLI	Command line interface
COS	Commercial off the shelf
CP	Control plane
CTMC	Continuous time Markov Chain
CUPS	Control plane user plane separation
DC	Data center
DDD	Domain driven design
DHCP	Dynamic host control protocol
E2E	End-to-end
ECMP	Equal cost multi-path
eMBB	Enhanced mobile broadband
eNB	The base station of the mobile system.
EPC	Evolved packet core
ICMP	Internet control message protocol
INT	In-band network telemetry
IoT	Internet of thing
IP	Internet protocol

ITU	International Telecommunication Unit
KPI	Key performance Indicators
LAN	Local area network
LiM	Link mapping
LP	Linear program
MILP	Mixed-integer linear program
MINLP	Mixed-integer non-linear program
MIQCP	mixed-integer quadratic constraint program
ML	Machine learning
MMPP	Markov-modulated Poisson process
mMTC	Massive machine type communication
MP	Mathematical program
MPLS	Multiprotocol label switching
MSA	Micro-service architecture
NBI	Northbound application interface
NEF	Network exposure function
NFV	Network function virtualization
NGPaaS	Next generation platform as a service
NIC	Network interface cards
NLP	Non-linear program
NoM	Node mapping
NOS	Network operating system
NRF	Network repository function
NS	Network slice
NSR	Network slice request
NSSF	Network slice selection function
NV	Network virtualization
OF	Openflow protocol
OPEX	Operational expenditure
PaaS	Platform as a service
PCE	Path computation element
PGW	Package data gateway
QoE	Quality of experience
QoS	Quality of service

RAN	Radio access network
RDB	Resource database
REST	Representational state transfer
RFB	Reusable function block
RPC	Remote procedure call
SBA	Service-based architecture
SBI	Southbound application interface
SGW	Service gateway
SID	Segment identifier
SLA	Service level agreement
SN	Substrate network
SOA	Service-Oriented Architecture
SOAP	Service-Oriented Architecture protocol
SPG	Shortest path graph
SR	Segment routing
SRA	Segment routing application
SRH	Segment routing header
TCP	Transport control protocol
TDF	Traffic detection function
TE	Traffic engineering
UDM	Unified Data Management
UDP	User Datagram protocol
UDSF	Unstructured data storage function
UP	User (data) plane
uRLLC	Ultra-reliable low latency communication
V2X	Vehicle to everything
VM	Virtual machine
VN	Virtual network
VNE	Virtual network embedding
VNF	Virtual network function
VNR	Virtual network request